Components of Biological Integrity: Their Definition and Use In Development of An Invertebrate IBI

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Abstract
Protection of quality water resources is critical to the maintenance of our way of life. Recent threats, such as the drought in California, fish consumption advisories, and contamination of beaches, are illustrative of the extent of abuse of water resources. These widespread declines in the quality of water resources have altered societal perceptions of and goals for the management of those resources. Growing interest in biological assessment in the last decade is in sharp contrast to the status quo of earlier decades. In this paper, we briefly review the evolution of water law and outline the conceptual foundations of ambient biological monitoring. We illustrate the use of those foundations as we outline our efforts to develop a methodology for use of invertebrates in assessing biological integrity.

Water Law

Early in this century, streams and lakes were viewed as sources of water or as locations for the discharge of societal wastes. Eventually, concern was expressed for the role of water pollution in the spread of human health problems; microbial contamination and oxygen-demanding wastes were early concerns and the threat of toxic contamination continues to expand.

As problems with and perceptions of water resources have changed, water law has changed as well. The first major water legislation in the United States was passed in 1889 to control oil pollution and protect navigation. Throughout the early part of this century and into the 1940's, legislative actions dealing with water resources tended to be relatively weak and provided little or no money. By the 1950's and 1960's legislation was tougher, but it concentrated on the development of construction grant programs to treat domestic effluent.

Passage of the Water Quality Act Amendments of 1972 (Public Law 92-500) brought a new approach with incorporation of the stated goal of protecting the fishable and swimmable status of these resources through control of point and non-point sources of pollution. Timetables, deadlines by which society had to respond to and protect water resources, were developed. For the first time, the phrase "biotic integrity" came into clean water legislation with the charge "to restore and maintain physical, chemical, and biological integrity of the nation's waters." But even that innovation did not stimulate a very broad perspective. The dominant approach continued to be control of chemical contaminants. Over the past decade the failure of that approach has become obvious. By the 1980's, new phrases such as "anti-degradation" and "ambient biotic assessment" were added to the lexicon of water resource professionals. Calls for adoption of biological criteria became common in the late 1980's (Karr 1991).

Overall, early legislative trends can be characterized by several common themes: an inordinate concentration on chemical contamination; funding for technology development and construction of wastewater treatment

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facilities; and increased enforcement efforts directed towards control of point-source pollution. Non-point sources of pollution were not seriously considered in water quality legislation until 1972. Even then, efforts to control non-point sources were relatively weak, primarily because they utilized point-source approaches and conceptual frameworks that are inappropriate for treatment of non-point source contamination (Karr 1990a).

Pollution Defined

The narrow contaminant perspective misconstrues the intent of the Clean Water Act. Pollution is defined in the 1987 Act as human "alteration of the chemical, physical, biological, or radiological integrity of water." That definition clearly goes beyond treatment of chemical contamination to a broader conception of factors responsible for degradation of water resources. An integral component of any effort to use that broad conception of pollution is the evaluation of the resource's ability to sustain a balanced biological community. If a water resource is degraded to the point that it does not support a healthy biological community, it very likely will not support one or more beneficial uses.

Assessing Water Quality

Toxicity testing and chemical evaluations of water samples have long been the mainstay of water resource evaluation. Each provides valuable information but, when conducted in the absence of ambient biological monitoring, they do not provide sufficient information to protect water resources. In a recent study, water chemistry data failed to detect 50% of the impairment in Ohio surface waters that was detected with integrated biological and chemical monitoring (Rankin et al. 1990). Thus, increased use of ambient biological monitoring is essential for the protection of water resources. Why has use of direct biological evaluations been so limited?

First, early efforts to maintain the quality of water resources were narrowly conceived and planned (Karr 1991). Water pollution control engineers dominated the agenda because chemical contamination was viewed as the problem. Water resource leadership was not familiar with, nor did it understand, the ecological dynamics that are important in influencing the effects of toxic compounds or other chemical contaminants. Further, they did not appreciate that degradation of water resources may be caused by factors other than chemical contamination. Ecologists and biologists must share the blame for inadequate incorporation of biological insights into water resource management. Most ecologists and biologists were either unable or unwilling to translate the foundations of their ecological knowledge into useable methodologies to evaluate the quality of water resources. The lack of a defensible conceptual definition of biological integrity also limited progress and use of biological monitoring. The phrase biological integrity was used in the Clean Water Act (PL 92-500), but development of a conceptual foundation was not vigorously pursued. The lack of standardized field methods to sample the biological community, to analyze the results of sampling, and the lack of procedures to synthesize that information into assessments of the conditions of a water resource also limited the utility and, thus, use of biological monitoring. Finally, misconceptions about the costs of biological monitoring perpetuated the idea that biological monitoring was too expensive.

The development of a broader perspective to ambient biological monitoring is critical to protection of water resources. Two concepts are important in the development of this broader perspective:

> **biological integrity** - "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition and functional organization comparable to that of natural habitat in the region" (Frey 1975, Karr and Dudley 1981).

ecological health - "... a biological system...can be considered healthy when its inherent potential is realized, its condition is stable, its capacity for self repair when perturbed is preserved, and minimal external support for management is needed " (Karr et al. 1986).

Evidence that biological integrity and ecological health are seriously threatened is widespread. Forty percent of the molluscs of the Ohio River drainage were listed as rare, endangered, or extinct by 1970 (Stansbery 1970). Two-thirds of the fishes of the Illinois River and 43% of Maumee River fish species have declined in abundance substantially or have disappeared in the last century (Karr et al. 1985). For the fishes of California, sixty-four per cent are in a list that ranges from extinct (6%) to declining populations (22% - Moyle and Williams 1989); only 36% of species have stable populations. In North America, 364 fishes warrant protection because of their rarity (Williams et al. 1989). Despite massive expenditures to improve water quality, none of 251 fishes listed as rare in 1979 could be removed from the list in 1989 because of successful recovery efforts (Williams et al. 1989).

As these examples demonstrate, water resources are still not adequately protected. Inadequately treated problems include toxics, non-point sources, habitat destruction, and altered stream flows. The limited use of biological factors in evaluating the quality of water resources perpetuates these problems and results in continuing declines in the health, the biological integrity, of water resource systems.

The Constituents of Biological Integrity

Weaknesses of most past approaches of biological monitoring include 1) a narrow conception of the factors responsible for degradation and 2) a limited perspective on the components of biological integrity. Over the past decade, my colleagues and I have identified five primary classes of variables that humans impact that result in the degradation of water resources:

1. Water quality - temperature, turbidity, dissolved oxygen, organic and inorganic chemicals, heavy metals, toxic substances, etc.

2. Habitat structure - substrate type, water depth and current velocity, spatial and temporal complexity of physical habitat.

3. Flow regime - water volume, temporal distribution of flows.

4. Energy source - type, amount, and particle size of organic material entering stream, seasonal pattern of energy availability.

5. Biotic interactions - competition, predation, disease, parasitism.

Karr et al. (1986, see also Karr 1991) provide a more detailed analysis of these factors and how human actions impact the quality of water resources. Among the five, water quality has been the primary subject of efforts by USEPA and equivalent state agencies. The U. S. Fish and Wildlife Service and state fish and game agencies have treated physical habitat degradation. In recent years, those same agencies evaluated altered flow regimes with the instream-flow methodology. Few have dealt with alteration of energy sources that drive stream biology, and most impacts on biotic interactions have come from efforts to introduce exotics and/or through harvesting of top predators. Overall, the determinants of water resource quality from a biological perspective are complex, and the simplistic EPA approach of making water cleaner is inadequate. We must evaluate all water resource degradation to identify the factors responsible for degradation and then treat the problem in the most cost-effective and efficient manner. Ambient biological monitoring offers unique opportunities to detect, analyze, and plan treatment of degraded resources.

Table 1. Components of biological integrity.

Elements	
	Genes within Populations
	Populations within Species
	Species within Communities/Ecosystems
	C/E within Landscapes
	Landscapes within Biosphere
Process	
	Nutrient Cycling
	Photosynthesis
	Water cycling
	Evolution/Speciation
	Competition/Predation
	Mutualisms

The components of biological integrity are also narrowly conceived by most individuals and agencies charged with protecting water resources (Karr 1990, in press). Two major aspects of biological systems - elements and processes - must be protected (Table 1). The most commonly cited aspects on the elements side are the species of plants and animals in aquatic communities. Additional critical components of the elements include the genetic diversity within those species and the assemblages (communities, ecosystems, and landscapes) upon which those species depend. At the level of processes, a myriad of interactions ranging from energy flow and nutrient dynamics to evolution and speciation are critical to the maintenance of biotic integrity. Given sufficient technology, we could maintain species in zoos and genetic diversity in gene banks but in the absence of complex species assemblages and the processes that keep them in existence, we are not protecting biotic integrity. The advantages of this approach to protecting the quality of water resources are diverse (Table 2).

Table 2. Advantages of ambient biological monitoring.

1. Broadly based ecologically
2. Provides biologically meaningful evaluation
3. Flexible for special needs
4. Sensitive to a broad range of degradation
5. Integrates cumulative impacts from point source, non-point source, flow alteration, and other diverse impacts of human society
6. Integrates and evaluates the full range of classes of impacts (water quality, habitat structure, etc.) on biotic systems
7. Direct evaluation of resource condition
8. Easy to relate to general public
9. Overcomes many weaknesses of individual parameter by parameter approaches
10. Can assess incremental degrees and types of degradation, not just above or below some threshold
11. Can be used to assess resource trends in space or time

Assessing Biotic Integrity

Critical components of a comprehensive approach to the protection of biotic integrity include evaluation of ecological attributes from the individual to the assemblage level. Further, an evaluation must be made with respect to the expectation for a relatively undisturbed natural habitat for that region, "regional reference site(s)." Within this framework, an efficient, accurate assessment of the status of the water resource is possible using biological monitoring. Further, an assessment is likely to detect degradation, regardless of the factor responsible for that degradation. Biological monitoring is at a threshold in the ways that it can be used and in the potential for development of methodologies and indexes that can provide useful answers to water resource problems. One of the most important contributions of the recent growth in interest in biological monitoring has been recognition of the need to set standards as a function of local and regional expectations. Indeed, that should have been done for chemical and physical criteria as well. For example, total phosphorus standards should vary regionally and according to primary use among Minnesota lakes with values ranging from less than 15 to 90 ug/l (Hieskary et al. 1987).

Many examples of use of ambient biological monitoring have been documented in the past decade (Karr et al. 1986, Ohio EPA 1988, Steedman 1988, Simon et al. 1988, Davis and Simon 1989, Davis 1990). Ohio EPA has been the most innovative and comprehensive in their development and use of biological monitoring (Ohio EPA 1988, 1990, Rankin et al. 1990, Ohio EPA 1991, Thoma 1991) but many other states are rapidly developing sophisticated approaches as well (e.g. Michigan, Wisconsin, Nebraska, Illinois, etc. - these proceedings). For example, in the Scioto River near Columbus, Ohio, a complex of water resource problems representative of many areas in the U. S. can be seen. Monitoring of the biota of the river over the last decade has shown substantial improvement in biological integrity in association with improvements in wastewater treatment plants (Fig. 1). However, because of the widespread degradation due to untreated factors (habitat degradation, non-point source pollution, input from combined sewer overflow), the biotic communities of the Scioto River adjacent to Columbus remain well below what might be expected in that region.

Successful efforts to protect water resources using biological monitoring have incorporated the following characteristics of biological systems: 1) their dynamics at a variety of relevant spatial and temporal scales and 2) appropriate metrics at three levels: a) ecosystem (productivity, decomposition, nutrient cycling, atmosphere/biosphere/geosphere interactions); b) population/community (community structure, species richness, species interactions, functional groupings, population structure); and c) health of individual organisms.

We must be innovative in incorporating these into water resource evaluations. Some can be incorporated directly and easily (e.g., population size, species richness) while others are more difficult or expensive to measure directly (Karr 1991). For example, the total productivity of an ecosystem is very difficult to measure. We should seek ways to measure productivity, or a surrogate of productivity that is indirect but reliable. Alternatively, we might develop more cost effective ways to measure productivity by improvements in technology.

Since early in this century, beginning with the work of Kolkwitz and Marsson (1907) and Forbes and Richardson (1928), Forbes (1919) and continuing to the present, biologists have noted a number of biological patterns associated with increased human influence within a watershed: the number of species declines, a small group of intolerant species disappear quickly, trophic specialists decline while trophic generalists increase. Effective biological monitoring can structure these general observations to define hypotheses (e.g, Table 3 for hypotheses implicit in IBI) and predictions about expected pattern in aquatic biota under varying levels of human influence. If after evaluating each hypothesis, we find general broad correlations, relationships between human disturbances and these attributes of the community, these then become assumptions. That is, we assume that, on average, these relationships accurately reflect the influence of human activities on natural communities. Thus, we have a fairly robust inference about the extent of degradation in biological integrity at a site.

Indexes of biotic integrity, such as IBI, are, thus, a quantitative expression of a number of known relationships between human disturbance and the characteristics of the resident biota. These indexes have four important properties. First, the accumulated information

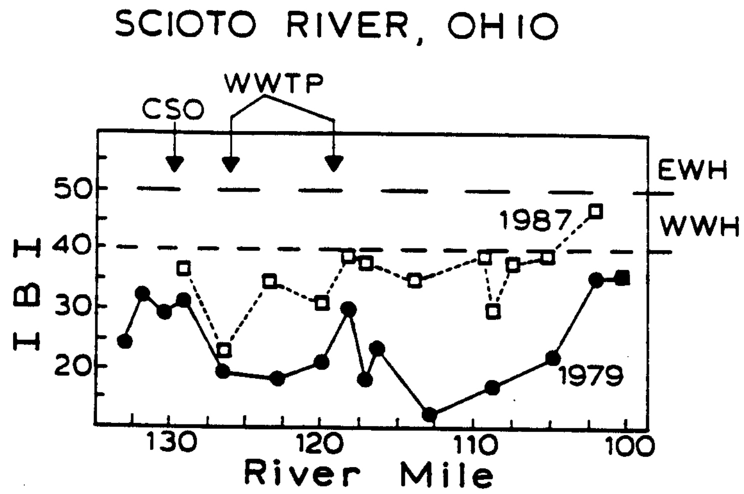

Figure 1. Longitudinal trend in IBI for the Scioto River, Ohio in and downstream from Columbus Ohio, 1979 and 1987. CSO = Combined sewer overflow; WWTP = Wastewater treatment plant inflow; WWH = Warmwater habitat; EWH = Excellent warmwater habitat. Stream flow is from left to right. (From Yoder 1989).

Table 3. Hypotheses/assumptions about biological patterns associated with increasing human effects on stream biota (modified from Fausch et al., 1990).

1. Number of native species and those of specific taxa on habitat guilds declines
2. Number of intolerant species declines
3. Proportion of individuals that are members of tolerant species increases
4. Proportion of trophic specialists such as insectivores or top carnivores declines
5. Proportion of trophic generalists, especially omnivores, increases
6. Fish abundance generally declines
7. Proportion of individuals in reproductive guilds requiring silt-free coarse spawning substrate declines
8. Incidence of hybrids increases
9. Incidence of externally evident disease, parasites, and morphological anomalies increases
10. Proportion of individuals that are members of introduced species increases

provides greater resolving power for the overall index than for each metric. The many components of biotic integrity (elements and processes) and the complexity of ecological systems, limits the likelihood that any single metric can be used to assess all forms of degradation and be sensitive across the full range of degradation. The magnitude of variation involved in assessments using only a single metric derives from natural variation and sampling error. As a result, no single metric is absolutely reliable in its ability to predict (with narrow precision) the state of biological integrity. A suite of metrics is better to insure more or less independent evaluations of site quality. Although site status is only generally known based on each individual metric (Fig. 2 upper), the addition of other metrics improves the resolving power of the approach; strong inferences can be made when multiple metrics are used (Fig. 2 lower). That is, each metric has a level of precision below 100% (perhaps 70-80%), but combining many metrics with that level of accuracy and across a variety of attributes of the biota, narrows the range and improves the precision of the estimate of biological integrity at a site.

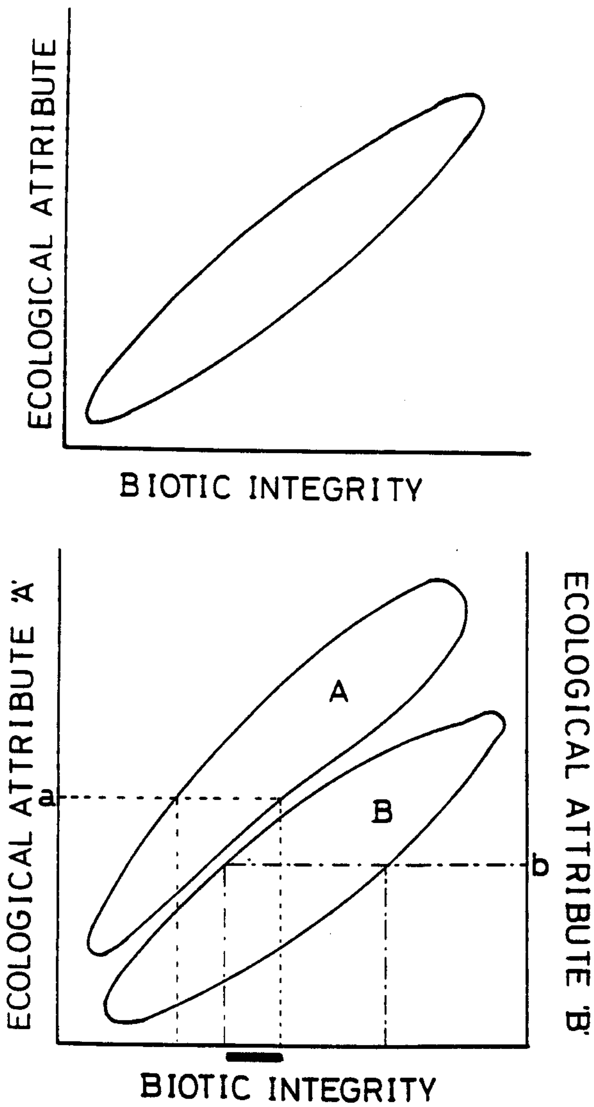

Figure 2. Conceptual depiction of the relationship between a single ecological attribute (IBI metric-upper panel) and two ecological attributes (lower panel)and biotic integrity. Note that simultaneous use of two metrics narrows the identified biotic integrity level (dark horizontal bar) relative to use of a single attribute (metric) (from Karr in press).

Second, the sensitivity of each metric varies with position along a gradient from undisturbed sites (high biotic integrity) to disturbed sites (low biotic integrity). Metrics such as total number of species seem to decline monotonically across the full range of degradation (Fig. 3). Intolerant species disappear before degradation has proceeded very far while the number of anomalies changes little until the area is severely degraded. In contrast, proportion of carnivores declines slowly with mild human impacts and declines rapidly at intermediate stages (Fig. 3). Carnivores disappear from a range of heavily degraded sites. Redundancies exist among metrics and relative sensitivities vary across the range of biotic integrity.

Third, biological monitoring as used in IBI acknowledges and accounts for natural geographic variation. Historically, that has not been done with physical/chemical parameters despite the reality of natural variation in those attributes. Accurate assessment of biological integrity requires fine tuning as one moves regionally. In fact, that is a major problem with historical chemical monitoring where expectations were not adjusted regionally. For many chemical attributes, failure to account for regional natural variation in contaminant levels is a serious error.

Fourth, evaluations attempted using the multimetric approach yield either narrative or numerical results (or both) to satisfy regulatory requirements.

Developing an Invertebrate IBI

The use of invertebrates to assess specific anthropogenic impacts on stream biota has a long history (e.g., Chutter 1972, Hilsenhoff 1977, Winner et al. 1980, Rosenberg et al. 1986). However, comprehensive attempts to evaluate stream biotic integrity using invertebrates have been attempted only recently (e.g., Hilsenhoff 1982, 1987, 1988, Ohio EPA 1988, Lenat 1988, Lang et al. 1989, Plafkin et al. 1989). Early in the 1980's Ohio EPA began to adopt the concepts involved in IBI for evaluations using benthic invertebrate communities. They developed a ten metric index (Invertebrate Community Index, ICI) that parallels the original IBI (Ohio EPA 1988). We applaud these approaches but feel that none combines metrics that evaluate both elements and processes of biotic integrity. Further, multimetric indexes have not involved evaluation of the robustness of the individual metrics. Thus, we outline our ongoing effort to develop a comprehensive invertebrate index for streams of the Tennessee Valley. We discuss 1) formulation of invertebrate metrics and 2) evaluation of the ability of individual metrics to determine biological integrity.

Our first task was to develop, a priori, metrics that characterize important elements and processes occurring in streams. We also intend to represent the full biological hierarchy from individual to community levels. Taxa richness (e.g., number of Plecoptera taxa) and community composition (e.g., proportion of tolerant organisms) metrics are the most widely used and highly developed metrics in existing invertebrate indexes (e.g., Ohio EPA 1988, Plafkin et al. 1989). Metrics designed to measure ecological processes and community function (e.g., proportion of grazers as a "surrogate" measure of periphyton production) have not been widely used nor fully investigated. Our goal is to investigate both types of metrics using stream benthic invertebrate databases provided by the Tennessee Valley Authority.

To develop metrics associated with ecological processes and community function we placed organisms (usually genera) into biotic categories describing trophic status, functional group classification, feeding mechanism, and habit (Table 4). Inclusion of trophic category metrics is usually not done, because most benthic biologists prefer categorization of stream organisms by functional-feeding group (Cummins 1973, Merritt and Cummins 1984). Our approach allows us to investigate how the dominance of grazer-scraper or omnivore guilds, for example, changes across sites. Inclusion of the habit biotic category allows us to examine patterns of loss of taxa in particular habitats. For example, sprawlers are usually associated with mineral substrate, while climbers are often associated with submerged or emergent vegetation.

Using the philosophy of the IBI, we developed 28 metrics in three distinct categories; taxa richness and community composition, trophic and functional group composition, and abundance (Table 5). Taxa richness and community composition metrics are often used in biological monitoring (Ohio EPA 1988, Plafkin et al. 1989). These include metrics like total taxa richness (Metric 1, Table 5), richness of intolerant insect orders (5, 6, 8), and the percent contribution of individuals in tolerant groups (15, 16) to the total community. As in IBI, taxa richness of intolerant groups often reflects levels of degradation (e.g., Lenat 1988).

Several taxa richness and community composition metrics relate to molluscs, an especially rich and sensitive group in the Tennessee Valley. Three involve native snail and long-lived mussel taxa (2, 3, 4). The mussel fauna of the Valley was thought to be the most diverse in the country and is declining (Isom 1969, Ahlstedt 1983, Starnes and Bogan 1988). Consequently, mussel taxa richness should reflect levels of biotic integrity. We also included two metrics that measure the proportion of Corbicula fluminea in the community (13, 14). The exotic Corbicula invaded the Tennessee River and its tributaries. Although there is some question as to the tolerance level of Corbicula, it certainly appears to be an "opportunistic" species (Prezant and Chalermwat 1984), and we hypothesize that it might be able to invade communities where other groups, especially native mussels, have declined.

Some metrics in the taxa richness and community composition category involve the number of taxa in specific habit categories. Skaters, planktonic organisms, divers, and swimmers spend most of their time in the water-column (9). Sediment-surface taxa (10)

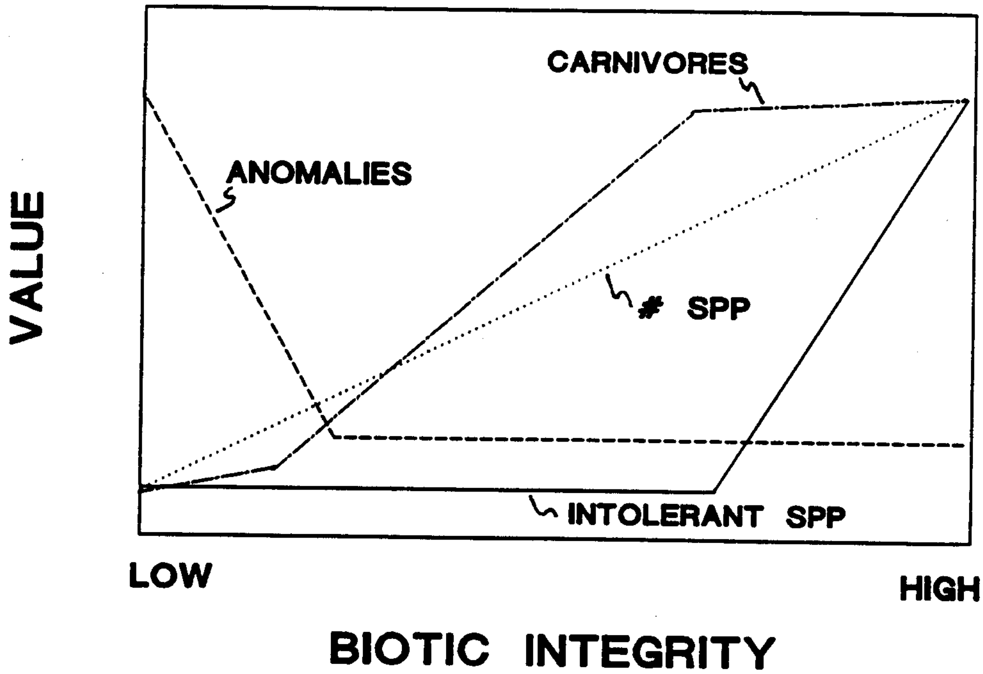

Figure 3. Conceptual depiction of the range of sensitivity of four IBI metrics across the gradient from low to high biotic integrity.

include clingers and sprawlers, whose lifestyles place them primarily on benthic substrates. Climbing taxa (11) spend much of their time on submerged or emergent vegetation or debris, while burrowers (12) live within the substrate. We hypothesize that declining numbers of taxa in the sediment-surface, water-column, and climbing guilds should reflect degradation of specific habitat types, while increasing taxa richness in the burrowing guild should indicate degradation. For instance, declining taxa richness in the group comprising the sediment-surface taxa should reflect degradation of the mineral substrate perhaps due to sedimentation.

Our second set of metrics includes two broad groups, trophic and functional-feeding group categories (Table 5). Although trophic categories are rarely used in benthic invertebrate studies, we include both trophic and functional group categories to increase the possibility of detecting change in the resource base of the community. Using trophic status, we hypothesize that we can determine how the detritus food base of the community, for example, changes by monitoring organisms in the detritus-feeding guild (18). We also can determine how collector-filterers (23) or grazer-scrapers (24; and their underlying resource base) change across sites. Finally, we included a metric, percent of individuals in the sample that are strictly predatory (26, consume only other animals in final developmental stages), to monitor the top trophic (and functional-feeding) levels in the community.

The third group, the abundance metrics, includes the total numbers of individuals (27)

Table 4. Biotic categories used in classification of invertebrates.

1. TROPHIC CATEGORY
   A. Herbivore
   B. Carnivore
   C. Detritivore
   D. Scavenger (Detritivore,Herbivore)
   E. Omnivore (Detritivore, Herbivore, Carnivore)
2. FUNCTIONAL GROUP*
   A. Shredder
   B. Collector
   C. Grazer
   D. Parasite
   E. Predator
3. FEEDING MECHANISM*
   A. Chewers
   B. Filterers
   C. Gatherers
   D. Scrapers
   E. Engulfers
   F. Piercers
4. HABIT*
   A. Skaters
   B. Planktonic
   C. Divers
   D. Swimmers
   E. Clingers
   F. Sprawlers
   G. Climbers
   H. Burrowers
   I. Attachers

* From Merritt and Cummins 1984

and the extent to which a single taxon or a few taxa dominate the community (28). These metrics have been used in other explorations of community assessment; however, their properties as individual metrics have been inadequately investigated. We explored a number of cutoff points (1-5 species) for the dominance metric, and at present are using the percent of individuals in the two most abundant taxa.

Our second objective is to determine how well each individual metric distinguishes biological integrity. To begin this process we examined individual metrics to determine if they vary predictably across rivers and streams monitored by the Tennessee Valley Authority. We use data from the Fixed Water Quality Monitoring Sites, an assessment program begun in 1986. Currently, there are sites on 12 tributaries of the Tennessee River; however, initially invertebrate data were collected for only six sites -- Clinch, Powell, Sequatchie, Elk, and Duck Rivers and Bear Creek. TVA used the fish IBI at four of these sites (Clinch, Powell, Sequatchie, Bear) and we have used IBI scores to make preliminary rankings (Clinch = Powell > Sequatchie > Bear) (Saylor et al. 1988, Saylor and Ahlstedt 1990). Our intuition is that the Elk and Duck Rivers probably fall between Sequatchie and Powell. We examined patterns of metrics across the sites (rivers). If a metric exhibits no discernable pattern or extreme variability across rivers (the four with "known" impact) then it is thought not to be able to distinguish sites. Using this approach, we deleted 10 metrics from further consideration (Table 5).

Although we looked at patterns for all our metrics, we discuss only a few. Total number of invertebrate taxa increases almost linearly from most degraded to least degraded sites (Fig. 4A). Surface-taxa richness shows the same pattern, probably indicating that the lost taxa occupy hard surfaces (Fig. 4B). The proportion of Corbicula (Fig. 5A) and proportion of collector-filterers (Fig. 5B) show reverse relationships, increasing from least degraded to most degraded sites. Corbicula increases dramatically only in the two most degraded systems, while collector-filterers increase almost linearly. These two metrics seem to provide differing areas of sensitivity to degradation, much as percent omnivores and percent anomalies do in the IBI (Karr, in press).

After we determine the relationships between our metrics and the levels of degradation at the

Table 5. Metrics proposed and being tested for inclusion in an invertebrate IBI.

POTENTIAL METRICS	HYPOTHESIZED TREND WITH DEGRADATION
I. Taxa Richness and Community Composition	
1. Total taxa richness	decline
2. Native snail and mussel taxa*	decline
3. Unionid taxa*	decline
4. Intolerant snail & mussel taxa	decline
5. Ephemeropteran taxa	decline
6. Trichopteran taxa	decline
7. Dipteran taxa*	increase
8. Plecopteran taxa	decline
9. Water-column taxa*	decline
10. Sediment-surface taxa	decline
11. Climbing taxa*	decline
12. Burrowing taxa*	increase
13. % individuals as _Corbicula_	increase
14. % bivalves as _Corbicula_*	increase
15. % individuals as oligochaetes	increase
16. % individuals as chironomids	increase
II. Trophic and Functional-Feeding Group	
17. % individuals as omnivores and scavengers	increase
18. % individuals as detritivores	increase
19. % individuals as herbivores*	decline??
20. % individuals as carnivores*	decline
21. % individuals as shredders	???
22. % individuals as collector-gatherers	increase
23. % individuals as collector-filterers	increase
24. % individuals as grazer-scrapers	decline??
25. % individuals as parasites*	increase
26. % individuals as strict predators	decline
III. Abundance	
27. Abundance	decline
28. % individuals in the two most abundant taxa	increase

*Metrics that have been dropped from further analyses.

Fixed Station Sites, we will test our metrics in one of two ways. First, water quality measurements have been taken on the Fixed Station Sites during the period of the invertebrate studies (Parr 1991). We will combine specific water quality data with information on land use practices occurring in each of the drainages and correlate these factors with our invertebrate metrics. This will strengthen our inferences concerning the ability of the metrics to distinguish degraded conditions. Second, we will independently evaluate individual metrics by applying them to data collected on other streams with known impacts.

Concurrently, we are exploring a number of properties associated with benthic sampling and level of taxonomic identification. For instance, at the Fixed Station Sites replicate samples are collected using different methodologies at each site; typically, several Hess samples (taken in pools and runs, the data presented previously), several Surber samples (taken in riffles), and qualitative samples (taken across all habitats) are available. We are evaluating the extent to which any one sampling method provides reliable evaluations of the biotic integrity. Our early conclusions suggest that Hess samples better differentiate sites than either Surber or qualitative samples. We also are interested in whether metric behaviors are consistent across stream size (headwater streams to large rivers), or if we have to score metrics differently as a function of stream size.

Our goal with respect to the development of an invertebrate community index is to investigate and test a number of hypotheses regarding individual metrics (as discussed above), score those metrics that seem to successfully reflect biological conditions, and develop an index from that based on a number from as few as 8 to as many as 14 useful metrics. After putting together an index that we feel is relatively reliable, we will seek data from areas of known impact to determine the ability of our invertebrate index to evaluate conditions resulting from varying human impacts.

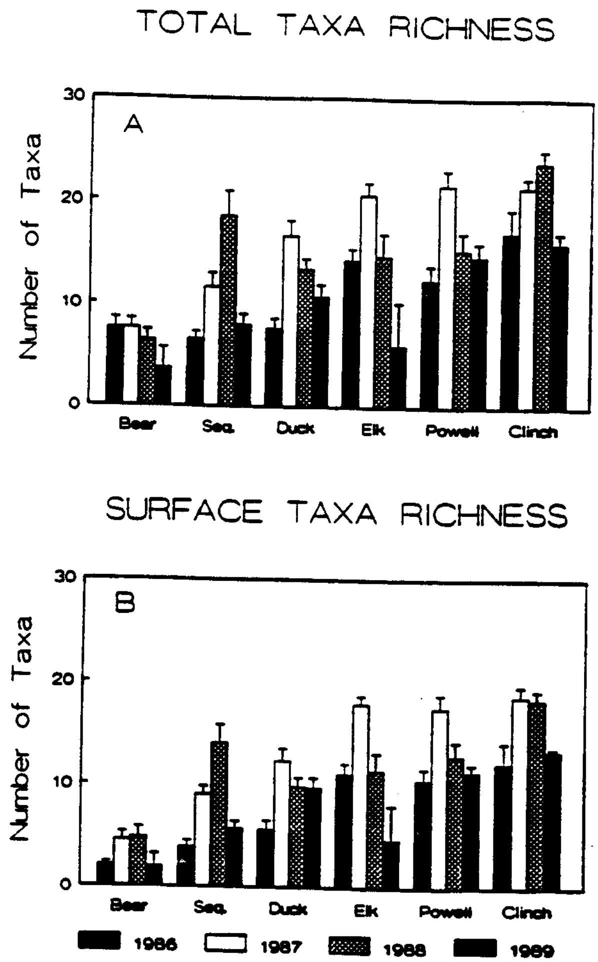

Figure 4. Mean and standard error bars for two invertebrate IBI metrics for six Tennessee River tributaries during four consecutive years (1986-1989). Note that the rivers are plotted from low quality (Bear Creek) to highest quality (Clinch River). A. Total Taxa Richness. B. Surface Taxa Richness. Both decrease with increasing human influence.

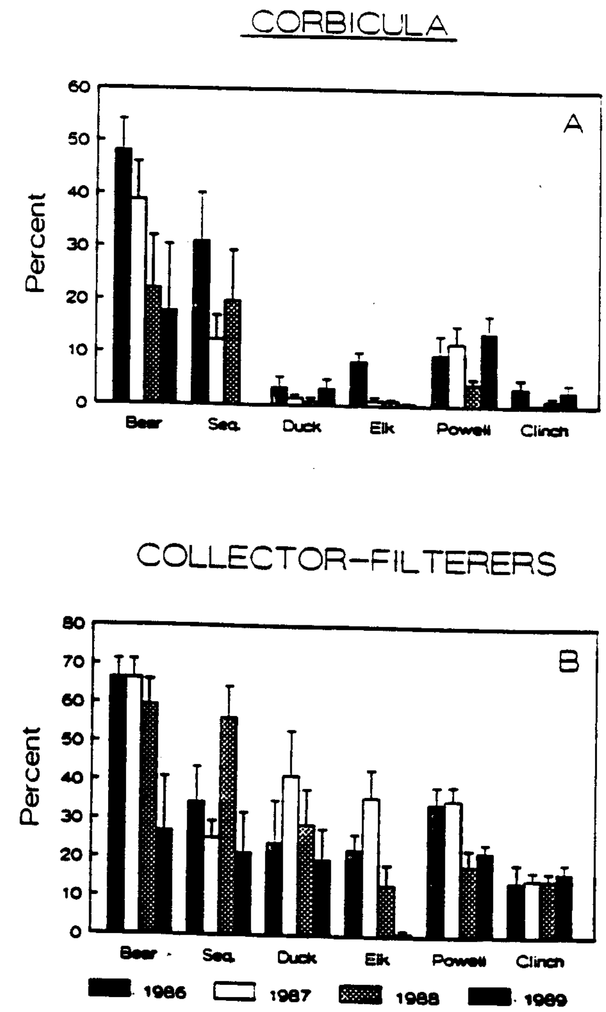

Figure 5. Mean and standard error bars for two invertebrate IBI metrics for six Tennessee River tributaries during four consecutive years (1986-1989). Note that Corbicula (A) increase, especially in the most degraded sites, while the collector-filterers (B) increase gradually along the gradient toward Bear Creek.

Summary

In closing, we want to emphasize three points. Historically, water chemistry and fish tissue sampling and toxicity testing have been the principal approaches used in the evaluation of water resources. Unfortunately, a number of forms of degradation imposed on aquatic resource systems by human society are not fundamentally chemical. As long as we depend solely on chemical analyses we are not likely to detect and treat the degradation caused by

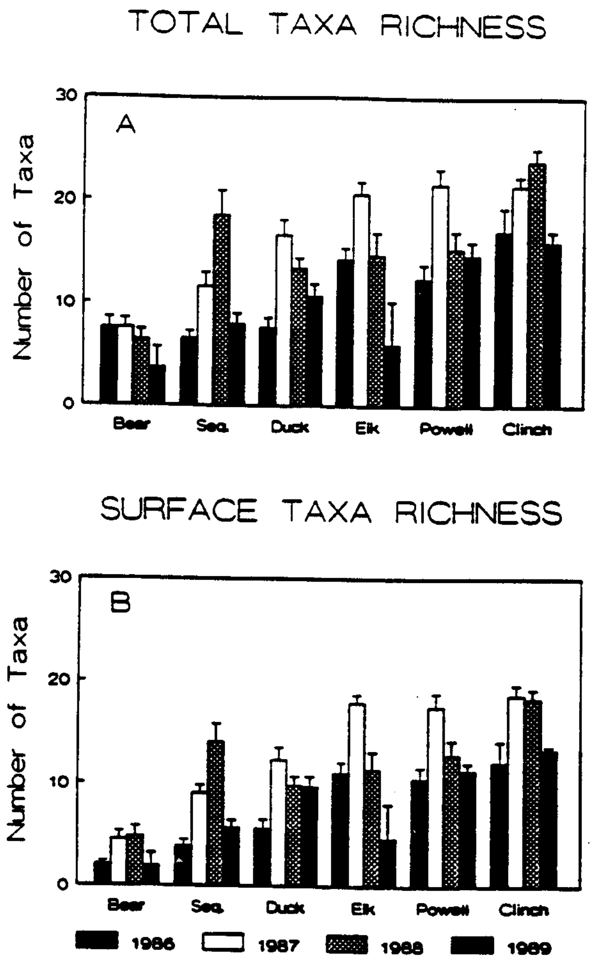

Figure 4. Mean and standard error bars for two invertebrate IBI metrics for six Tennessee River tributaries during four consecutive years (1986-1989). Note that the rivers are plotted from low quality (Bear Creek) to highest quality (Clinch River). A. Total Taxa Richness. B. Surface Taxa Richness. Both decrease with increasing human influence.

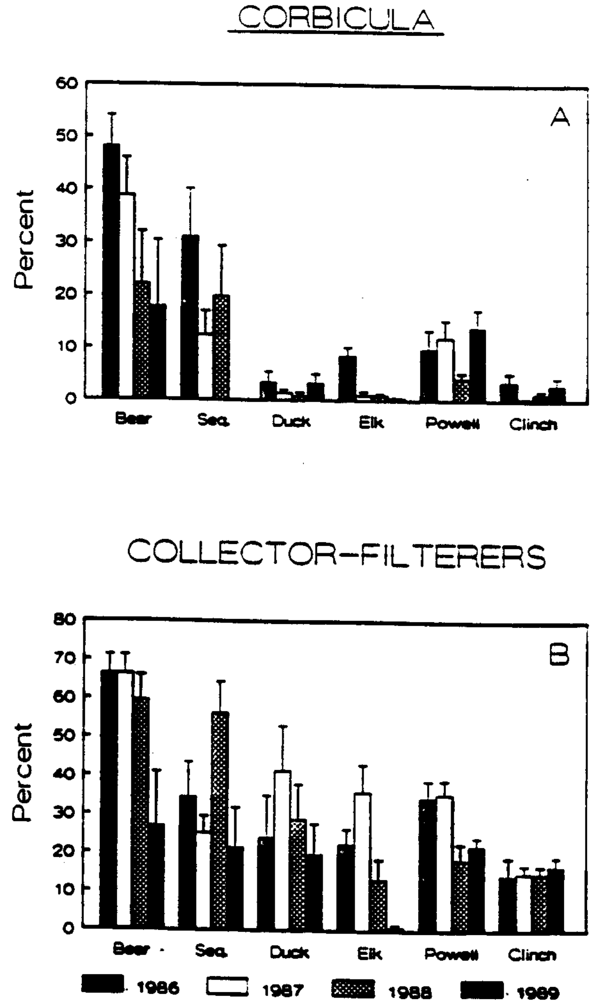

Figure 5. Mean and standard error bars for two invertebrate IBI metrics for six Tennessee River tributaries during four consecutive years (1986-1989). Note that Corbicula (A) increase, especially in the most degraded sites, while the collector-filterers (B) increase gradually along the gradient toward Bear Creek.

Summary

In closing, we want to emphasize three points. Historically, water chemistry and fish tissue sampling and toxicity testing have been the principal approaches used in the evaluation of water resources. Unfortunately, a number of forms of degradation imposed on aquatic resource systems by human society are not fundamentally chemical. As long as we depend solely on chemical analyses we are not likely to detect and treat the degradation caused by those factors. We view the array of water quality or water resource sampling programs as a tripod (some have inappropriately compared it to a three-legged stool). With a tripod, the relative length of the legs (monitoring approaches) can be altered to suit the landscape of local water resource problems.

Second, a number of major transitions during the past decade have stimulated rapid changes in societal approaches to water resource protection. Assessment of water resources today is broader than the assessment of the chemical quality of the water, a development that was precipitated by the widespread recognition that the quality of water resources continues to decline. The broader societal goals for the protection of water resources requires the use of the broader range of disciplines to inform water resource decisions. Furthermore, decisions based on a narrow disciplinary approach often must be questioned when placed in the larger disciplinary context. As a result, the dogma of many disciplines is under more careful scrutiny. The dogma of the past cannot be accepted uncritically if we are to properly protect water resources. The planning perspective in protection of water resources is expanding in both space and time. Planning should be done for periods of decades, not for next year. Planning can and should be done over entire watersheds, not over short river reaches. The emergence of a landscape ecology view of water and other natural resources is instrumental in making society aware of the need to plan in a wider geographic context.

The role of biology will continue to expand. The most important challenge is for biologists and ecologists to be more effective at translating the knowledge about biological systems into the tools that can be used by society in protecting the biological and non-biological components of those water resources (Karr 1991).

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